Machinery Messages ·····························

TOOLBOX TIPS
When you use spectrum, don't use it halfway

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Requirements for effective machinery diagnostics

Successful and cost-effective diagnosis of machinery malfunctions requires the right type and quantity of data. Without the right data, you can't produce the information you need to understand what your machine is doing, and a fully systematic diagnosis of machine malfunctions is impossible. This is unsatisfactory in today's highly competitive industrial and commercial environment. Bently Nevada has the solutions required to eliminate this problem.

You can draw an analogy between machinery diagnostics and the process of installing and maintaining a rotating machine. To install and commission the machine successfully, you need the data and information contained in the manufacturer's manuals and installation drawings. In addition, you need the right tools to complete the job. In fact, to do the work in a quality fashion, you need a full toolbox, with all of the right tools. A screwdriver is great for driving screws — but you need wrenches of different sizes to tighten nuts.

The same concept applies to machinery diagnostics — you need data and information. Some of the information you need can come from observation of the machine's construction and application (including the details of process parameters). Data from our vibration transducers needs to be converted into information through the use of various presentations or plots. These plots are the tools in our diagnostics toolbox.

Think of Bently Nevada's machinery diagnostic systems — ADRE® for Windows, Machine Condition Manager™ 2000, and Data Manager® 2000 for Windows NT — as very well-equipped "electronic toolboxes." The different plots are useful in different ways, just like any other kind of tool.

In this article, we will discuss half spectrum plots and full spectrum plots, how they differ from other plots and how they can be effectively used in conjunction with other plots, such as an orbit/timebase plot. Remember, if you don't use all of the tools, or misapply any of them, you will not get the high quality diagnosis you need.

Let's open the half spectrum and the full spectrum drawer of the Bently Nevada ADRE® for Windows toolbox and discuss these tools, what they are, how they differ and how they are used properly.

What is the difference between half spectrum and full spectrum plots?

A half spectrum plot has the same relationship to a full spectrum in the frequency domain that a timebase plot has to an orbit in the time domain. Half spectrum and timebase plots use data from a single transducer to provide frequency, amplitude, and phase information. Full spectrum and orbit plots use data from two orthogonal transducers and provide additional information on the direction of precession and ellipticity of the orbit, unique and significant vibration characteristics.

Half spectrum plot

A half spectrum plot is produced when a Fast Fourier Transform (FFT) is used in a vibration analyzer to derive the frequency components present in the vibration waveform. Spectrum plots show information about the frequency and amplitude of components of the vibration signal. Two spectrums can also provide relative phase information, needed for locating the source of a fluid-induced instability, for instance. However, absolute phase information, which is available only when a
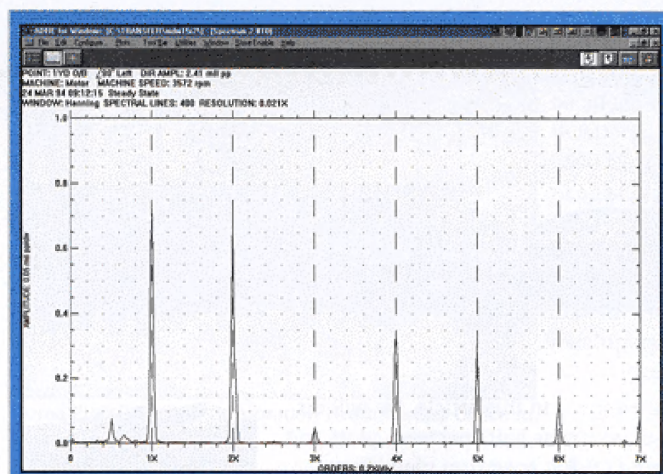
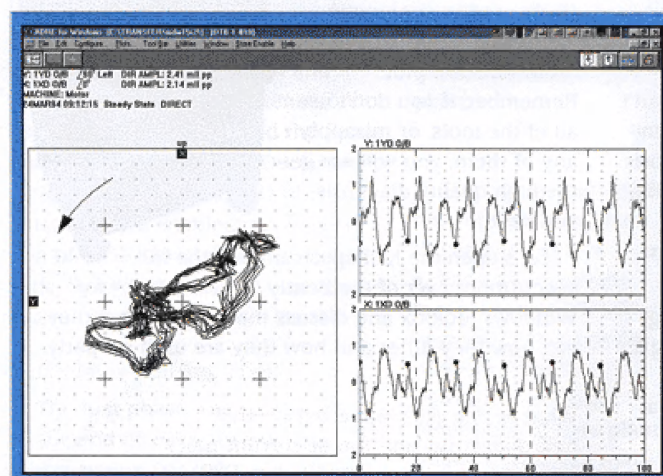Figure 1. Half spectrum plot for Y probe.

Figure 2. Orbit/timebase plot for the XY probes.

Keyphasor® transducer is used, and relative phase information can be viewed more conveniently using other plot formats. For example, orbit/timebase and amplitude/phase/time (APHT) plots are especially relevant for studying the 1X and 2X vibration amplitude and phase information.

The half spectrum plot (Figure 1) is a frequency domain version of a timebase plot. The half spectrum plot makes identification of frequencies and individual component amplitudes easier, but the timebase plot reveals the *form* of the vibration signal by incorporating amplitude, frequency, and phase information. *The form of the signal is important to verify that the signal is meaningful.* Otherwise, a half spectrum plot can be very misleading — an FFT analyzer will process any signal it is given. If the signal is corrupted by noise, the resultant spectrum

will contain identified frequencies which are meaningless. Techniques, such as averaging, are used to improve the accuracy of a half spectrum plot. However, no amount of averaging can make a useful plot from a corrupted or spurious vibration signal.
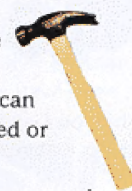
When only one vibration measurement is made at a particular location on a machine, the half spectrum plot is useful, provided you also have timebase plots to verify the vibration signal quality. An example would be using an accelerometer on a gearbox for studying gear mesh effects. When there is only one frequency present in the signal, it is easy to determine the frequency from the timebase plot. You don't need the half spectrum plot. However, when there are several frequencies present, you need the half spectrum plot to determine all of the individual frequencies and the amplitude of each. One vibration signal will not allow you to create a full spectrum format, though.

Full spectrum plot

When you have two vibration transducers in an XY orientation (orthogonal measurement axes) at a measurement location, you now have several unique tools in your toolbox in addition to the individual timebase and half spectrum plots for each transducer signal. If the XY transducers are shaft displacement probes observing a rotor, the orbit/timebase plot is very widely used and understood. XY shaft displacement probes are essential for machines with fluid film bearings (turbines, compressors, pumps, etc.). The orbit/timebase plot clearly identifies the form of the vibration and the motion of the rotor centerline relative to the two probes. You now have a much more powerful tool for machinery diagnostics.

The direct (unfiltered) orbit/timebase plot for the two probes in our example is shown in Figure 2. The orbit/timebase plot is quite complex; the shape is far from circular, and there is certainly more than one frequency present in the orbit and the timebase traces.

The full spectrum plot (Figure 3) is an FFT of X and Y vibration signals, with a well-defined relationship with the timebase and orbit plots. By using the FFT more effectively, the full spectrum plot can clearly indicate the direction of procession and degree of ellipticity of the orbit.

Orbit / timebase

Point: Bearing 1 vibration vertical (Y)

Point: Bearing 1 vibration horizontal (X)

2.0 mil/div X to Y (CCW) Rotation   5.00 ms/div   4935 rpm

Orbit / full spectrum

1.0 mil/div X to Y (CCW) Rotation

Amplitude (mil pp/div)

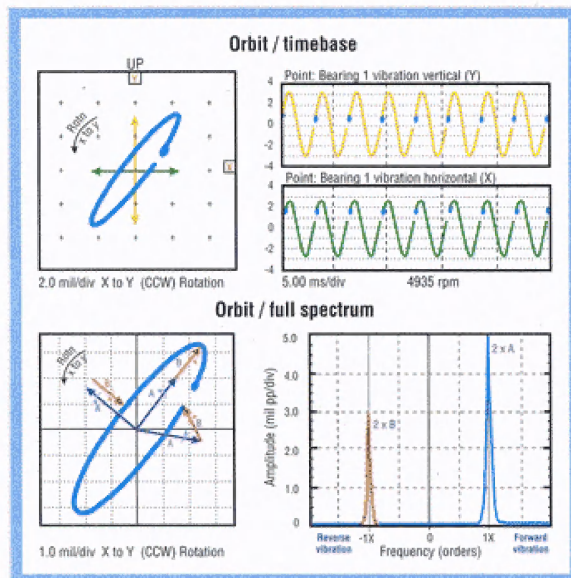Reverse vibration   Frequency (orders)   Forward vibration

Figure 3. *Top* - Orbit plot is generated from the X and Y timebase values. *Bottom* - the full spectrum is generated from the amplitude and frequency values (at each discrete frequency) of the two (forward and reverse) vectors whose sum is the ellipse (orbit).

In the familiar orbit/timebase plot, the Keyphasor signal is used to determine rotor speed and, more importantly, to enable you to determine the phase and direction of precession of the orbit relative to the direction of rotor rotation. Both forward and reverse precession are possible. Forward precession occurs when the phase sequence of the vibration signals from the XY probes is the same as the direction of rotor rotation. A reverse precession plot occurs when the phase sequence is reversed relative to the rotational direction.

If the orbit is relatively simple (only one or two frequencies present) or if the orbit is 1X or 2X filtered, the direction of precession of the orbit can clearly be seen. When the vibration signal contains several frequencies, as in this example, it is more difficult to determine the direction of precession and the amplitude of individual vibration components using only an orbit/timebase plot. This is when the full spectrum tool is really useful, because vibration com-

ponents are identified, not only in terms of frequency and amplitude, but also in terms of their *direction of precession.* Forward components are shown on the right hand side of the full spectrum plot and Reverse components are shown on the left hand side (Figure 4).

Frequencies (or nX orders of running speed) on the right of the frequency origin are positive, and those on the left are negative. Caution: The right hand side of the full spectrum plot appears to be the same as a half spectrum plot for one probe. *This is not true* since only forward components are shown on the right side of the full spectrum plot.

As fully described in Bently Nevada literature and training material, the identification of several machinery malfunctions depends on knowledge of the direction of precession of orbits at discrete frequencies or orders of running speed (nX). Using full spectrum plots in conjunction with orbit/timebase plots helps you determine the direction of the precession of various vibration components in the overall signal.

What does it mean when a particular vibration signal has both a forward and reverse component of the same frequency? Depending on the relative amplitude of the right hand (positive) and left hand (negative) components, you can determine the form or shape of the orbit at that particular frequency, and its direction of precession. This information is also contained in the orbit/timebase plot, of course. However, if there are sev-
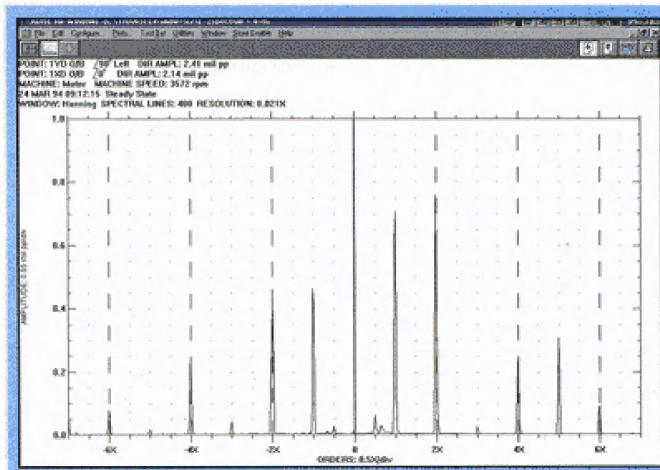
Figure 4. Full spectrum plot for XY probes in Figure 2.

eral frequencies present, the shape of the orbit may be more difficult to see. In the full spectrum plot, a forward circular orbit is represented by a component only present on the right hand side.

A reverse circular orbit has a component only on the right hand side. When the components on the right and left hand sides are equal or of different amplitudes, this tells you that the orbit at that frequency is elliptical. When the amplitudes are equal, the orbit is a straight line, the most elliptical shape. The greater the difference in amplitude, the more circular the orbit. The component with the larger amplitude determines the direction of precession of the orbit; a reverse component which is larger means reverse precession. An elliptical orbit indicates that the restraints on the rotor are not equal in all directions, which may be an indication of unequal bearing stiffness or the presence of a force on the rotor (due to misalignment or a fluid-induced sideload, for example).

The angular orientation of the major axis of an elliptical orbit is also important to help determine the direction of the stiffness or force. However, this is where the orbit/timebase plot becomes the correct tool for the job. A filtered orbit/timebase plot clearly indicates the angular orientation of the orbit major and minor axes. For the same XY probe data we have been discussing, the 1X and 2X filtered orbit/timebase plots (Figures 5 & 6) document the orientation and confirm the highly elliptical shape and direction of precession indicated by the full spectrum plot (Figure 4).

Summary

When you have a single vibration signal to analyze (for example, when studying a rolling element bearing or a gearbox mesh condition), the half spectrum plot and the timebase plot should be used *together*, along with other relevant information about the machine. When you have XY vibration probes, for example, XY shaft displacement probes located at a fluid film bearing, the full spectrum plot and orbit/timebase plots should be used *together*. Don't use two half spectrum plots for each of the two XY probes — valuable information is lost and the effectiveness of the diagnostic process is reduced.

Returning to the toolbox analogy, you should use different tools to do different tasks. You wouldn't use a screwdriver to hammer a nail. Our Machine Condition Manager 2000, Data Manager 2000 for Windows NT and ADRE for Windows software systems are very useful
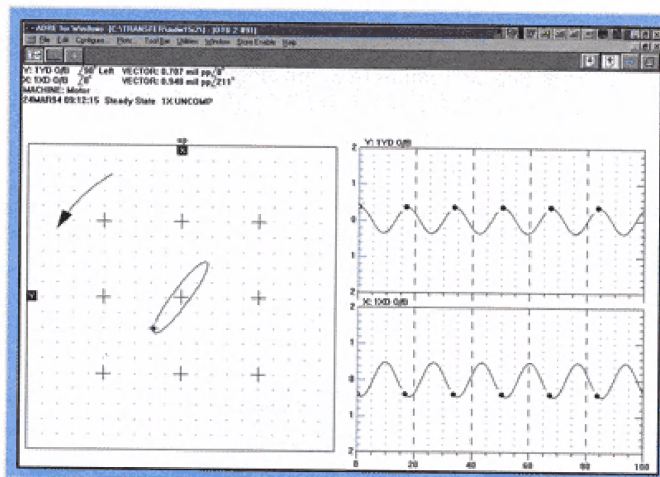
Figure 5. 1X orbit/timebase plot showing elliptical orbit with forward precession, as well as orientation of the major axis. Compare with 1X components in full spectrum plot (Figure 4).
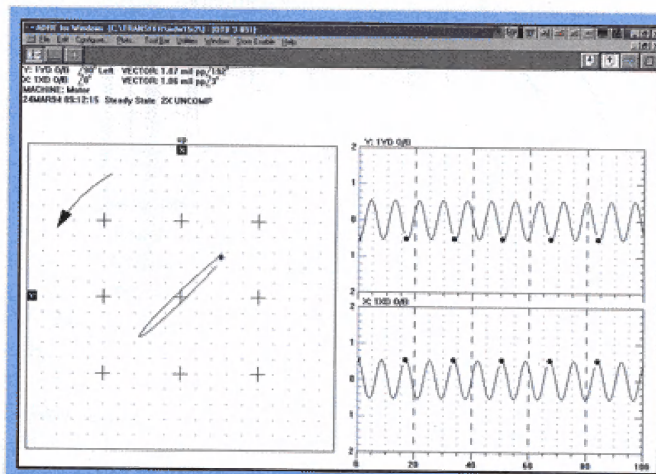

Figure 6. 2X orbit/timebase plot showing elliptical orbit with forward precession, as well as orientation of the major axis. Compare with 2X components in full spectrum plot (Figure 4).

electronic tool boxes, as they contain the new full spectrum tool.

Watch for the article in the September 1998 *Orbit* about how the full spectrum is derived.

For more information on these products, contact your nearest Bently Nevada sales representative. ↺

References:

1. Southwick, D., "Using Full Spectrum Plots," Orbit, Vol. 14, No. 4, December 1993, Bently Nevada Corporation.
2. Southwick, D., "Using Full Spectrum Plots Part 2," Orbit, Vol. 15, No. 2, June 1994, Bently Nevada Corporation.
3. MachineLibrary™, Bently Nevada, 1997.